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ANALYSIS OF THE FAILURES OF THE SELECTED BUS SUBSYSTEMS RESULTING IN DANGERS WITHIN A TRANSPORT SYSTEM[1]

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The paper deals with the analysis of bus subsystem failures and with the evaluation of their influence on the dangers to the human health and life and the environment. In order to perform the evaluation, the failure mode and effects analysis (FMEA) method has been applied, which consists in determining the failure occurrence probability and its effects related to a technical object or its subsystems under the investigation. This method is useable to determine the dangers within the utilisation process. The investigations have been carried out with the use of a randomly chosen sample of the technical object within a real operation and maintenance system of the municipal transport buses.

Keywords: Safety, risk, reliability.

1. Introduction

This paper attempts to evaluate the dangers arisen in the process of using the vehicles, resulting from incorrect operation of the municipal transport bus subsystems. On the basis of the analysed relevant literature and our own investigations it has been found that the reasons of the dangers in the antropotechnic systems may be as follows:

- failures of the bus subsystems (components),
- operator's (driver's) faults,
- roadway co-users' faults,
- inappropriate infrastructure of the roadways and improper condition of the roadway surfaces,
- atmospheric conditions, etc.

The subject of this paper is analysis of impact of the bus subsystem failures on the dangers within the human-technical object-environment (H-TO-E) system. The effects of the failures of the technical objects analysed cause various dangers to the people as well as degradation of the environment.

[1] Praca wykonana w ramach projektu badawczego KBN nr 1254/T12/2002/22.

The dangers may be measured by evaluating the risk, resulting from such failures, due to which a technical objects takes the states, considered in this paper as being dangerous. In these states a vehicle may be a subject to a breakdown or an accident, thus causing danger to the human health and life and to the environment.

The term of risk is related to such terms as: damages, danger and undesirable events. One of the most important terms related to the risk is danger, which is to be understood as a possibility of generating loos as a result of an occurrence of a single undesirable event (PN-IEC 60300-3-9, 1999; Radkowski, 2003). An undesirable event (dangerous one) is defined as an event which may cause a damage (Radkowski, 2003).

A damage according to (PN-IEC 60300-3-9, 1999; Radkowski, 2003) is defined as a physical harm to the health, property damage or environment degradation.

The risk is a combination of a possibilities of occurrence of an undesirable event and the effects measured by the extent of the losses the risk causes.

The evaluation of the risk level depends on the knowledge of the processes taking place within the antropotechnic systems and the quality of the information on the states of these processes. Therefore, it is a process combined of the series of logical steps, in which the dangers related to the analysed technical object are investigated in a well ordered way.

One of the most important risk measures is probability that the losses occur in the adopted time interval of operation of the considered H-TO-E system.

The measures of the risk, described in the relevant literature, are applied in general in order to describe its levels assuming that the losses occur in an unexpected (sudden) way for instance due to accidents and other random reasons. If the losses are caused due to long-lasting harmful factors such as: noise and vibrations, than the health loss rate depends on the duration the harmful factors act upon the human organism.

The dangers caused by operation and maintenance of the buses in a transport system of a municipal bus transportation may be divided into two types in general:

- to the people (related to the loss of the health or life of the passengers and drivers as well as of people which are within a vehicle surroundings),
- to the environment caused by emission of: operation and maintenance fluids, exhaust gases, noise, vibrations.

2. Purpose

The purpose of the paper is evaluation how the failures of the selected bus subsystems affect creation of the danger states in an antropotechnic system.

3. Investigation object

The object of the investigation is a real municipal bus transport system within a large agglomeration. The analysed system operates and maintains 210 municipal buses of various makes and types. The main aim of the system is passenger transportation over the city area and within the suburban zone.

The essential requirements for the systems of such a type are as follows:

- providing safe passenger transportation and minimising emission of agents being harmful to the environment,
- realization of transport services over the preset routs,
- realization of transport services according to the preset schedule (punctuality and frequency).

4. Operation and maintenance investigations

The operation and maintenance investigations have dealt with thee selected bus types, being in use in the analysed municipal bus transport system. The analysis has covered the dangers and the failures of the elements and subsystems of those systems which had been assumed to be the most important from the point of view of the risk level evaluation. The individual buses have been randomly selected from a set of the technical objects being operated and maintained within the investigated system. The operation and maintenance investigations have been carried out with the use of passive experiment method in the natural conditions of operating and maintaining the means of transportation. 21 buses of 3 different makes have been selected for the investigation purposes. The investigations covered one-year long operation and maintenance of the vehicles.

5. Risk level evaluation methodology

Some of the methods to analyse the risk are subject to standardisation, e.g. standardised methods: FMEA (Failure Mode and Effects Analysis) – network method of a failure analysis, ET/OU – network analysis method with dividing an object into structural elements, FMECA - modified FMEA method, also called AMDEC, which consists in searching critical elements – weak links in the TO.

As a result of the analysis of the selected risk evaluation methods (FMEA, ET/OU, FMECA) of generating a risk when operating and maintaining the means of the urban transport, the FMEA method has been selected for the investigation purposes because of its application easiness combined with simultaneous possibility of obtaining exact representation.

The FMEA method consists in determining the probabilities of occurrence of the failures and breakdowns and the effects related to their occurrence with respect to the analysed antropotechnic system or its subsystems.

This method consists in determining the risk level of the dangerous events occurrence (R) depending on the probability that a failure or a breakdown of a TO subsystem (P) occurs, evaluation of this fault effect index (Z) and failure detectability index (W).

In this paper a method related to the probability of detecting the TO subsystem failure has been applied.

The evaluation of the risk level with the use of FMEA method is carried out in more or less detailed way according the actual need. This is performed by determining the risk value R (Radkowski, 2003) with the following formula (1):

$$R = P \cdot W \cdot Z \tag{1}$$

where:

R – risk evaluation index,
P – failure occurrence probability index,
W – detecting failure by a driver index,
Z – index of damaging vehicle subsystem (component) effects or of the operator's fault effects,

The value of the P, W, Z indexes is normalised to be within the range of $\langle 1 \div 10 \rangle$. Further actions depend on the risk level value R (Safety and Degradation of Machines. First Conversatorium, 1995). High risk level value R should be the basis to take appropriate actions aimed at minimising occurrence of a failure (Radkowski, 2003). The Table 1 indicates proposed exemplary values of the P, W, Z indexes, applied to set the risk value.

Table 1. Exemplary values of the P, W, Z indexes applied to evaluate the risk (Radkowski, 2003)

Failure occurrence probability – failure may take place (occurrence)		Detectability index – fault may be detected (occurrence)		Failure effects index - interaction (significance)	
P		W		Z	
Improbable	1	High probability	1	Almost imperceptible	1
Very slightly probable	2÷3	Moderate probability	2÷5	Slight load	2÷3
Slightly probable	4÷6	Slight probability	6÷8	Moderately medium fault	4÷6
Moderately probable	7÷8	Very slight probability	9	Severe fault	7÷8
Highly probable	9÷10	Improbable	10	Extremely severe fault	9÷10

On the basis of the analysis of the relevant literature and our own investigation the Table 2 shows proposed index values applied to evaluate the risk based on which points are assigned. The value of the assigned points depends on the condition of the technical object, the operator's knowledge level and the detection efficiency.

Table 2. Assumed correlation between the number of the assigned points and the event occurrence probability value

Number of points	Event occurrence probability	Probability value
1	Very slight	0,001÷0,0049
2-3	Slight	0,005÷0,049
4-5	Moderate	0,05÷0,099
6-7	Frequent	0,1÷0,149
8-9	High	0,15÷0,179
10	Very high	> 0,18

6. Investigation results

The operation and maintenance investigation results regarding the evaluation of the influence of the selected subsystems failures on the dangers within H-TO-E system as well as the data concerning the risk level value for the selected bus sample are presented in the Table 3.

Table 3. Values of the risk level, P, Z, W indexes of the subsystems selected from the investigated buses

Name of the damaged subsystem/component	Indexes										
			Ikarus IK280			Volvo B10BL			Jelcz M11		
	W	Z	*P*	P	R	*P*	P	R	*P*	P	R
running gear											
Tyres	*8*	*10*	0,02682	2	**160**	0,031496	3	**240**	0,036671	3	**240**
Wheek	*1*	*9*	0,015326	2	18	0,03937	3	27	0,002821	1	9
Fastening bolts	*1*	*9*	0,003831	1	9	0	1	9	0,00141	1	9
Set of wheels	*1*	*10*	0,003831	1	10	0,015748	2	20	0,00141	1	10
Front axle system	2	*8*	0,007663	2	32	0	1	16	0,009873	2	32
electric											
Electric leads	*1*	*6*	0,157088	6	**36**	0,267717	6	**36**	0,255289	10	**60**
Alternator	*3*	*5*	0,034483	2	30	0,015748	1	15	0,021157	3	45
Starter	2	2	0,019157	2	8	0,016845	2	8	0,059238	4	16
Accumulators	*1*	*6*	0,011494	2	18	0,016487	1	6	0,066291	4	24
Lighting	*1*	*10*	0,065134	3	**30**	0,299213	10	**100**	0,101551	6	**60**
Alternator V-belts	2	*5*	0,065134	3	30	0,125984	4	40	0,043724	3	30

Name of the damaged subsystem/component	**Indexes**										
			Ikarus IK280			**Volvo B10BL**			**Jelcz M11**		
	W	Z	P	P	R	P	P	R	P	P	R
braking											
Brake master cylinder with hoses	*1*	*10*	0,044687	3	30	0	1	10	0,293371	10	**100**
Brake callipers	2	*8*	0,027732	2	32	0,008765	2	32	0,088858	5	80
Servomechanism	*3*	*8*	0,012134	2	48	0	1	24	0,002821	1	24
body											
Passenger seats	*1*	*8*	0	1	8	0	1	8	0,009873	3	24
Passenger door suspension system	*1*	*10*	0,042612	4	40	0,07874	5	50	0,081805	5	50
Passenger door control system	*1*	*10*	0,061303	4	40	0,062992	4	40	0,070522	5	50
Mirrors	*1*	*8*	0,003831	1	8	0	2	16	0,043724	3	24
Others	*3*	*6*	0,042146	2	**36**	0,094488	5	**90**	0,22426	10	**180**
suspension											
Suspension air-bag	2	*9*	0,021917	2	36	0,098328	5	90	0,019746	2	36
Levelling valve	2	*9*	0,015791	2	36	0,062298	4	72	0,047955	3	54
Others	*4*	*8*	0,011494	2	**48**	0,139842	7	**224**	0,077574	5	**160**
steering											
Steering rod	*1*	*10*	0,003441	1	10	0,014478	2	20	0	1	10
Steering system – hydraulic hoses	*3*	*9*	0,022339	2	**54**	0	1	**27**	0,016925	2	**54**
Steering system – others	*3*	7	0,004231	1	21	0	1	21	0,002821	1	21

In order to evaluate the risk level values for the individual subsystems (assemblies) of a vehicle, their failure analysis has been performed. For the said purpose an urban bus had been decomposed into 10 subsystems (assemblies) such as: engine, drive transmission, running gear, electric system, braking system, body, steering system, compressed air supply system, suspension system and others.

After performing preliminary data analysis, only the most important subsystems in terms of the evaluation of the risk level value have been selected. The Table 3 shows the investigation results for the most important subsystems in terms of the risk value.

Symbol Designation:

W – failure detectability index

Z – failure effects index

P – failure occurrence probability

P - failure occurrence index

R – overall evaluation of the risk level

7. Results analysis and conclusions

An event consisting in a damage to the tyres in the running gear system of the investigated vehicles is characterised by the highest risk level value in terms of the random nature of such type events occurrence. The risk value in this case is R=240.

However, the greatest influence on the risk value in the braking system have failures of such subsystems as: servomechanism and pneumatic system controlling brake shoe expander. The risk level reaches high values in case of Jelcz M11 buses.

High danger level may be caused by the failures of the suspension subsystem elements and of the steering system, for which the value of the failure occurrence probability index P is the highest. High value of the risk level index is characteristic for the failure of an air-bag in the suspension subsystem, for which R index takes the value exceeding 160. The R value is by several times lower for the failures of other elements of the suspension subsystem.

The highest impact on the value of the body risk level have failures of the following subsystems and elements: door control and suspension, seat fastening, mirrors. Attention should be brought to the high value of the failure effect indexes for those elements.

Also high risk level value is characteristic for the failures of the electric installation subsystem: head-lights, bulbs and electric leads, in all the investigated vehicle types.

The analysis of the dangerous events provides us with information on the dangers taking place in the operation and maintenance process of the antropotechnic system and on the failures of the most important bus subsystems.

In the FMEA method to evaluate the risk level, slight changes of the index values related to the failure occurrence probability P, failure detected by the driver W and effects of the failures of a vehicle subsystem (element) Z cause significant changes of the risk value R, described with the formula (1). The risk level may take significant values also when the value of one of the components of the product P*W*Z is high. Therefore, when evaluating the risk value, the values of the remaining indexes are to be analysed as well. For that reason it is needed to evaluate the influence of the damaged elements on the bus subsystems and to determine the effects of those failures which lead to dangers.

Efforts are to be taken to minimise primarily those dangers which affect human organism, and subsequently lead to other losses. Therefore, it is needed to identify weak links in the system and take actions aimed at removing them or try to limit the dangers they create within the H-TO-E system. One of the methods may be to equip the vehicles with the systems monitoring the condition of the most important elements in terms of safety, thus helping the operator in the process of detecting the failures.

The investigations are to be carried within longer time interval, since not all important elements had failures within the analysed period of time. Therefore, the analysis results may be incomplete, though the proceeding methodology adopted in this paper is correct.

When performing these investigations attention should be brought to the effects of those dangers which have negative impact on the human organism. It is such an important problem, since new dangers may occur as a consequence of those effects.

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Monografia zawiera wybór artykułów dotyczących informatyzacji procesów zarządzania, prezentując bieżący stan rozwoju informatyki stosowanej w Polsce i na świecie. Zamieszczone artykuły opisują metody, algorytmy i techniki obliczeniowe stosowane do rozwiązywania złożonych problemów zarządzania, a także omawiają konkretne zastosowania informatyki w różnych sektorach gospodarki. Kilka prac przedstawia wyniki projektów badawczych Ministerstwa Nauki i Informatyzacji, dotyczących rozwoju metod informatycznych i ich zastosowań.

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